7.0 AEROMECHANICAL CHARACTERIZATION

BACKGROUND

The Aeromechanical Characterization Action Team (Aeromechanical AT) is responsible for fostering collaboration between individual HCF programs and test opportunities with the goal of providing the required design and test verification focus for the entire HCF S&T program. The Aeromechanical AT provides technical coordination and communication between active participants involved in HCF testing technologies and the Test and Evaluation Plan under development at Arnold Engineering Development Center (AEDC). Annual technical workshops have been organized, and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Aeromechanical AT members meet annually to review technical activities, develop specific goals for test and evaluation programs, and review technical accomplishments. The Chair (or Co-Chair) reports to the Technical Plan Team (TPT) and National Coordinating Committee (NCC) on an annual basis. The secretary of the TPT is informed of AT activities as needed. This AT includes members from government agencies, industry, and universities who are actively involved in technologies applicable to turbine engine HCF. The team is to be multidisciplinary, with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT will change as individuals assume different roles in related programs.

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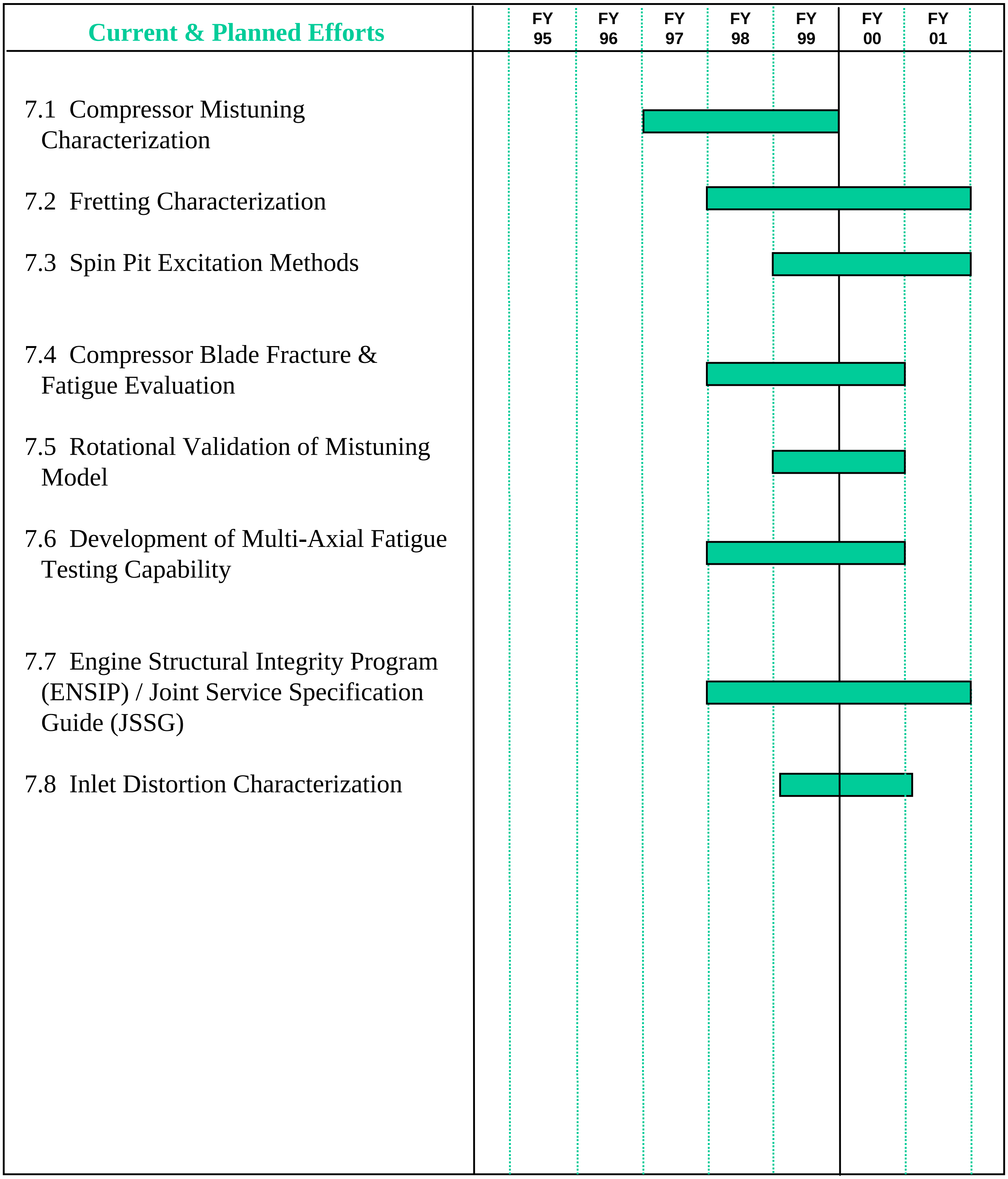
INTRODUCTION

The following pages summarize the schedules, descriptions, and progress of the current and planned projects managed by this action team.

Aeromechanical Characterization Schedule



7.1 Compressor Mistuning Characterization

FY 97-99

Background: The objectives of this task are to characterize mistuned response at speed in an integrally bladed disk, or blisk, and to compare experimental results to mistuning code predictions. The findings can be used to evaluate and improve mistuning prediction codes for more accurate prediction of stresses and stress variations. Research is currently applied to fans but may also be extended to compressors and turbines. Structural variations in turbomachine blades cause variations in the natural frequencies of the blades, known as mistuning. Mistuning leads to mode localization, which can cause dangerously high resonant stresses in a single blade or group of blades. Various factors including manufacturing tolerances, wear, and unsteady aerodynamics can affect the mistuned response. Measurement of the mistuned response and characterization of the factors influencing the response is necessary to develop accurate stress prediction models that account for the effects of mistuning.

Recent Progress: Testing of the rotor has been completed, and the mistuned response of the blisk has been characterized for the modes of interest. Mistuned response was affected by different factors for different modes. Aerodynamic coupling dominated the mistuned response at the first blade mode. Comparison to the model yielded significant qualitative insight but indicated a need for improved modeling of aerodynamic effects. The second and third modes occurred at nearly the same frequency, resulting in mode interaction as shown in Figure 56. Because of this, these modes were difficult to characterize, both experimentally and analytically. Results have indicated a need for additional modeling of mode interaction and unsteady aerodynamics, as well as improved physics-based modeling of the fundamental structural mistuning problem. Experimental characterization efforts for this project are now concluded until further developments in modeling are achieved.

$\omega = 1224$ Hz $\qquad\qquad$ $\omega = 1225$ Hz

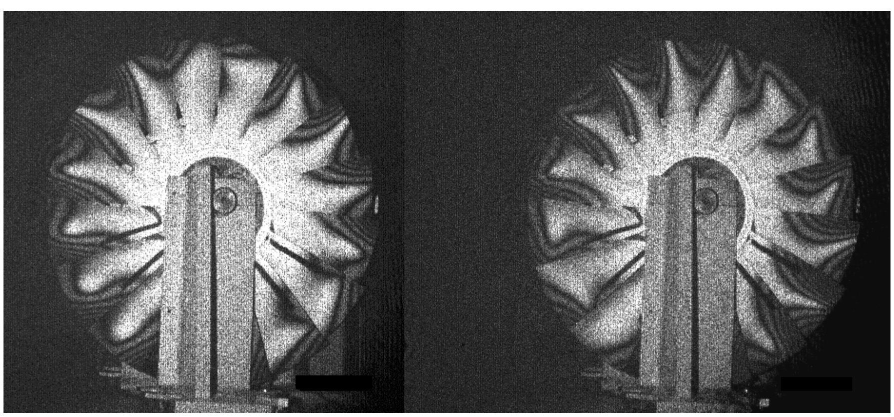


FIGURE 56. 2B/1T Mode Interaction.

Participating Organizations: Air Force Research Laboratory

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7.2 Fretting Characterization
FY 98-01

Background: The objective of this task is to develop an understanding of the mechanical drivers in fretting fatigue and develop techniques to minimize their impact on material behavior. In particular the metal-to-metal dovetail attachment of blade and disk attachments will be studied. Fretting fatigue is approximately 6 percent of all HCF failures. The elimination of this problem correlates to six million dollars ($6,000,000) per annum saved in maintenance costs.

The primary mechanical life drivers will be established through a systematic variation of various contacting bodies, the first of which will be "dog bone" specimens placed into contact by cylindrical pads. Different contact loads will be applied to determine the effect of the applied loads on fretting fatigue. Fatigue parameters will be evaluated as to their ability to predict the number of cycles to crack initiation, crack location, and crack orientation along the contact surface. The evaluation process will provide the basic mechanisms for fretting fatigue crack initiation for metal to metal contact. The second phase of the program will concentrate on real blade-disk geometry. Simulated contact surfaces will be loaded in a manner similar to those experienced in a turbine engine environment. The fatigue parameters developed for fundamental surfaces will be evaluated and modified as necessary to predict fretting fatigue on the real blade-disk geometry. Subsequent programs will then explore techniques to minimize the detrimental effects of fretting fatigue in turbine engines.

Recent Progress: To date, 96 "dog bone" specimens have been fabricated and tested to failure. Fatigue parameter evaluation has been completed on the simplified geometry. A single fir tree specimen, which is symbolic of the real part, is currently being modeled via finite element analysis. A fretting fatigue parameter has been developed based on the interaction between a plain fatigue specimen and a simplified pad geometry. It has been determined that fretting fatigue crack initiation occurs on the plane of maximum shear stress amplitude and that it is dependent on the amount of slip at the crack location. A simulated blade dovetail and disk slot (single fir tree component) have been modeled and CAD drawings have been developed for machining.

The simulated blade-dovetail and disk slot will be tested in order to assess the accuracy of the fretting fatigue mechanisms determined through the simplified geometry approach. The robustness of the predictive model will be evaluated by considering the crack initiation behavior on the single fir tree component. The final phase of fretting fatigue research will involve employing methods such as coatings and compressive residual stresses in order to alleviate the fretting damage induced at the blade disk interface. The estimated completion date is September 2001.

Participating Organizations: Air Force Research Laboratory, Air Force Institute of Technology, Pratt & Whitney

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7.3 Spin-Pit Excitation Methods

FY 99-01

Background: The objective of this task is to develop a reliable and controlled method for exciting and measuring blade and rotor resonance modes of interest using a spin-pit test. Steady-state blade excitation in a spin pit will enable potential HCF problems and fixes to be addressed early in the development cycle of a rotor. This capability will provide a low-cost alternative to the expensive verification tools (rig and engine testing) currently in use.

Recent Progress: A contract with Test Devices was awarded in June 1999, and the kick-off meeting was held at their facility in July. The meeting was attended by Pratt & Whitney, General Electric, Rolls-Royce Allison, the Navy, and the Air Force, who all have interest in the technology and are involved to some degree in the effort.

Several methods of blade excitation were considered in the initial phase of this contract. A ranking of these methods was accomplished based on their likelihood of success and practical considerations for implementation. The result was a down-select to four methods, including low density air jets, liquid jets, fog jets, and condensing jets.

These four methods will now go through a series of analyses and experiments to select the most promising concept(s). A small four-bladed rotor is being designed with removable instrumented blades to further evaluate the concept(s). A full-scale rotor spin test will then be performed at the end of the contract to demonstrate the steady-state blade/rotor excitation system.

Participating Organizations: Air Force Research Laboratory (AFRL), Naval Air Warfare Center (NAWCAD), Test Devices Incorporated

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7.4 Compressor Blade Fracture and Fatigue Evaluation

FY 98-00

Background: The objective of this effort is to determine the enhancement capabilities of Laser Shock Peening (LSP) on Foreign Object Damage (FOD) tolerance and HCF resistance when applied to real gas turbine engine compressor blades. A series of F100-PW-229 fourth-stage compressor blades will be evaluated. LSP-treated and untreated blades will be driven to failure at a resonance condition on a shaker table. FOD damage will be simulated on some of the LSP-treated and untreated blades by machining a notch at the leading edge of the blade. The fatigue life of the LSP-treated and untreated blades with and without the simulated FOD will be compared to determine the damage tolerance enhancement of LSP.

Recent Developments: All airfoils to be evaluated have been delivered to the Turbine Engine Fatigue Facility (TEFF) at Wright-Patterson AFB. Testing of the airfoils began in 1999 with approximately 12 airfoils fatigued before experimental problems developed. The shaker system will be back on-line in early 2000 and testing will resume. Testing will be completed on the F100-PW-229 fourth-stage airfoils in FY00.

Participating Organizations: Air Force Research Laboratory (AFRL)

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7.5 Rotational Validation of Mistuning Model

FY 99-00

Background: The objective of this task is to validate the REDUCE reduced ordered mistuning model developed at the University of Michigan under the GUIde Forced Response Consortium. Initial evaluation using engine hardware (see Section 7.1 above) has been performed, and the reduced order modeling code has shown promise in predicting mistuning response in full engine hardware. However, full validation of the model in needed and will allow for more complete understanding of structural mistuning and application of this code in the HCF test protocol.

In this study, a simulated bladed disk assembly (Fig. 57) will be intentionally mistuned based on the reduced order model predictions, and then experimentally evaluated. Validation data will be obtained from bladed disks under stationary and rotational conditions. Stationary data will be obtained through laser vibrometry at the University of Michigan. Additional stationary and rotational test data will be acquired using strain gages, holography, and SPATE in the vacuum chamber of the Turbine Engine Fatigue Facility of AFRL. The experimental results from the mistuned disks will be compared to the reduced ordered modeling predictions.

Experimental equipment is in place at both the Air Force Research Laboratory and the University of Michigan. Design of final test articles is complete and the disks are currently being machined. Testing of the components should begin in early 2000.

Recent Progress: No activity was reported in 1999.

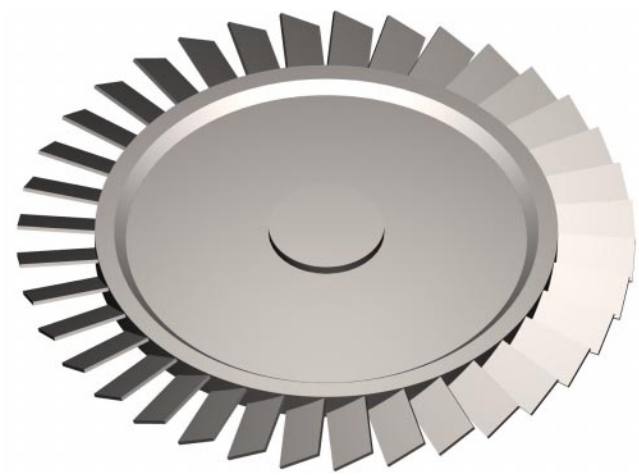

FIGURE 57. Mistuning Validation Simulated Bladed Disk

Participating Organizations: Air Force Research Laboratory (AFRL)

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7.6 Development of Multi-Axial Fatigue Testing Capability

FY 98-00

Background: The objective of this task is to develop the capability to test turbine engine components in a bench-test environment that simulates vibrational loading effects experienced during engine operation. Research goals are to develop a test system that simulates operational blade loading and to develop a data acquisition system that will accurately monitor critical test parameters. This test capability will provide a low-cost method to evaluate turbine engine blades for HCF.

A test fixture (Fig. 58) was designed and constructed to test gas turbine blades under biaxial loading conditions. A load cell on the primary axis was employed to simulate the centrifugal loading experienced by the blade. A ram on a second axis allowed for vibrational loads simulating bending to be induced in the airfoil. Combined, the loading allows for fatigue testing under simulated operational environments. In Phase II, the concept is being extended for multi-axial fatigue. Two rams are positioned on the second axis, and depending on their relative position, either bending or torsion can be induced in the airfoil.

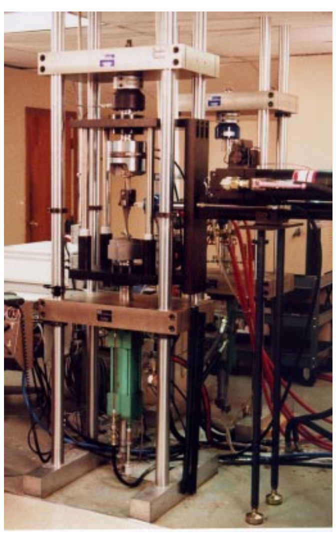

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FIGURE 58. Proof of Concept Biaxial Fatigue Fixture

Recent Progress: The design of the multi-axial fatigue frame (Figure 59) was completed in early 1999. Installation in the Turbine Engine Fatigue Facility (TEFF) began in August 1999 an is now complete. Shakedown of the system and initial testing is underway. Testing of fan blades will begin in early 2000.

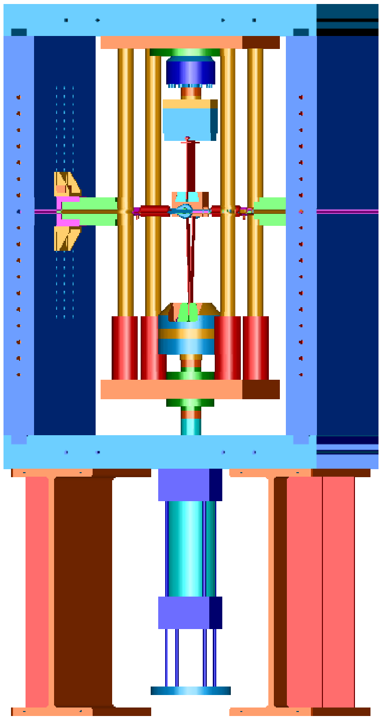

FIGURE 59. Multi-Axial Fatigue Model

Participating Organizations: Air Force Research Laboratory (AFRL)

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7.7 Inlet Distortion Characterization
FY 99-00

Background: The objective of this project is to develop a technique to produce inlet flows that simulate conditions experienced in-flight. This will improve the fan system development process for aeromechanical evaluation of blade vibrations due to inlet flow distortions. As a result of this effort, aeromechanical risks to fan systems will be reduced by implementing a proper test and evaluation technique to simulate appropriate inlet flow field conditions, which are similar to those experienced in flight. The outcome of this program will be incorporated in the HCF test protocol. The technical challenge is to accurately predict the inlet flow distortion and the resulting unsteady forces experienced by a fan. In particular, key modeling requirements need to be determined for defining the excitation types on the fan's vibratory response. The approach is use data analysis and computational analysis methods of flight, ground, and model tests of the F-16/F110, and the model test data of an Advanced Compact Inlet System (ACIS).

Recent Progress: The initial data analysis of roughly 50 conditions from the flight tests of the F-16/F110 flight data has given a correlation of vibe stress versus excitation strength, defined by a Modal Excitation Index (MEI), as shown in Figure 60. This stress versus MEI correlation is based on the use of the two rings of total pressure measurements obtained during the flight test. It does NOT include the effects of distortions in other flow variables, namely static pressure and flow angularity.

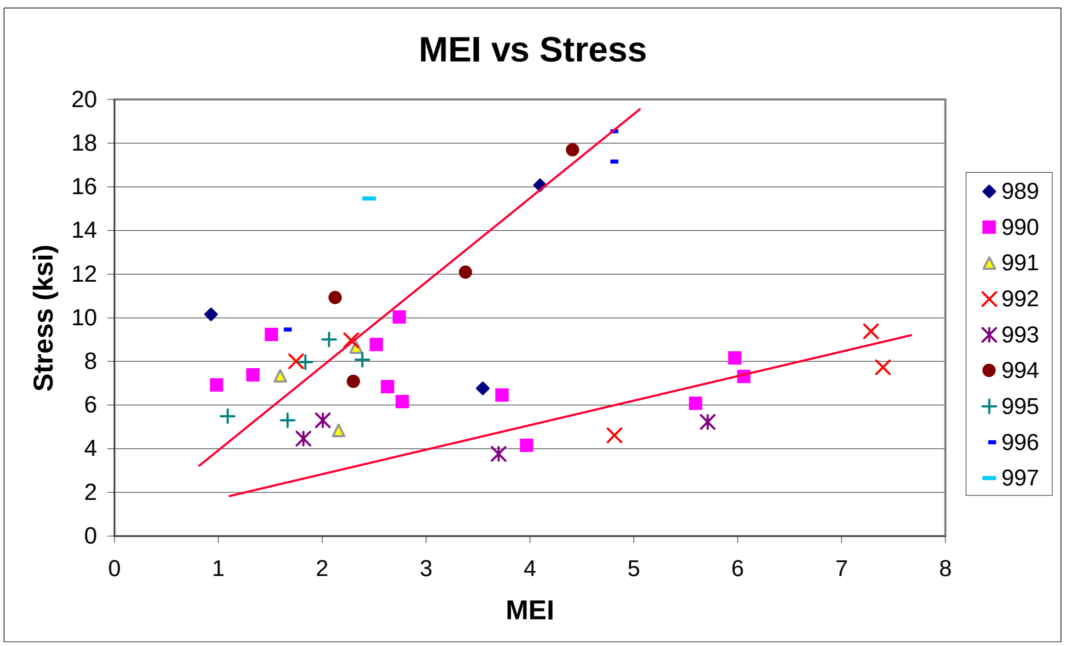

FIGURE 60. Initial Correlation between Vibratory Stresses and Modal Excitation Index (MEI)

This initial attempt shows the potential of being able to use the MEI method to correlate with vibratory stress. However, two distinct, linear curves are shown in the correlation. Further analysis was performed to determine if the source of the different correlations is from the inability to accurately resolve the distortions radially with only using two rings of information. To help demonstrate this, Figure 61 shows the comparison between predictions obtained from computational fluid dynamics (CFD) predictions and the measurements for the supersonic, deceleration condition. This is one of the highest vibe stress cases in the above correlation, Figure 60. As can be seen the excitation (distortion) increases dramatically at roughly 85% span which is further outward in radius than the outer of the two measurement locations.

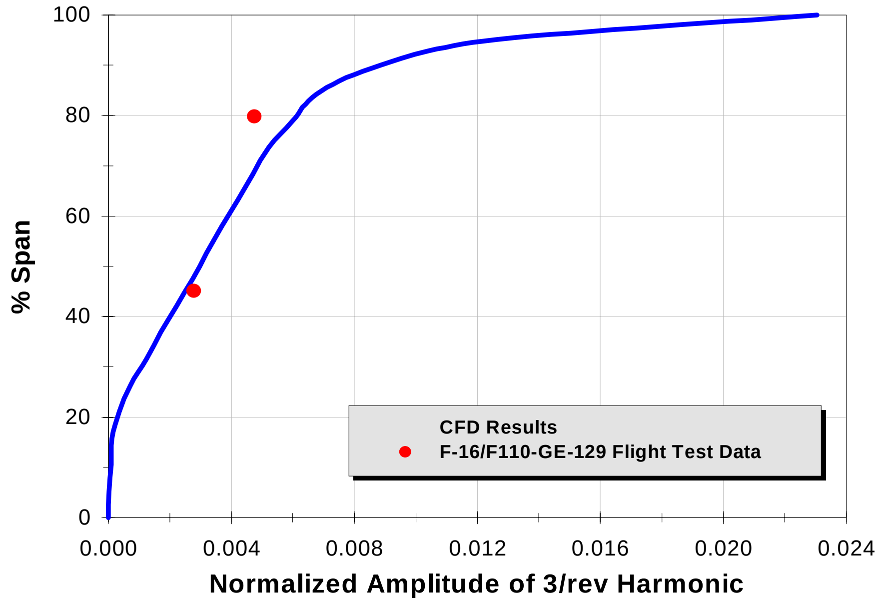

FIGURE 61. CFD Prediction and Measurements of 3/rev of Supersonic, Decel

To determine if this is the possible cause of the two correlation trends seen in Figure 60, the radial distribution from the CFD results was matched to the data and the MEI calculation was performed. The resulting MEI was increased roughly by a factor 2 to 3. As seen in the modified correlation of Figure 62, this causes the supersonic, cruise data point (1a) of the upper curve to be a better match (Point 1b) the trend of the lower curve. Thus, this implies that the two correlation trends are due to some flight conditions having important distortion content in regions at higher radius than the measurements.

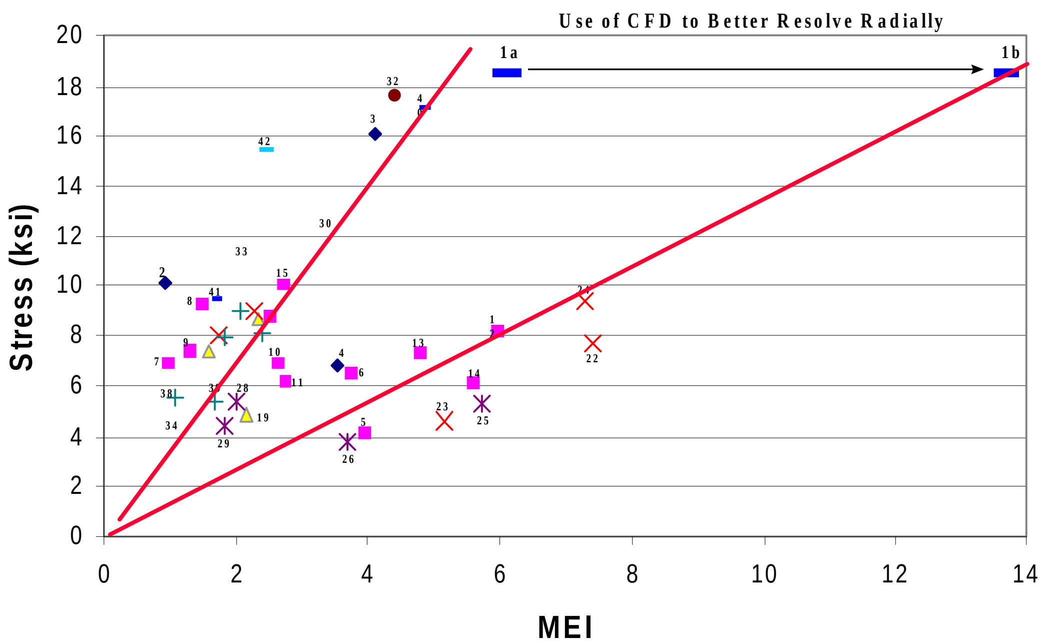

FIGURE 62. Modified Correlation between Vibratory Stresses and MEI

Participating Organizations: Aeromechanics Technology

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7.8 Engine Structural Integrity Program (ENSIP) / Joint Service Specification Guide (JSSG)

FY 98-01

In 1998, an effort was undertaken at the recommendation of the Executive Independent Review Team (EIRT) to update JSSG-87231 and MIL-HDBK-1783A (the ENSIP Manual) with what we have learned as a result of the HCF initiative. Three teams ("Analysis," "Testing," and "Materials") were formed to look into what changes were needed. The teams worked throughout 1998 and early 1999 formulating their recommendations.

In 1999, it was decided to update the ENSIP Manual first. The three teams began providing recommendations in May 1999. A series of draft revisions have been made to the ENSIP Manual based on these recommendations. Some of the updates include new analyses for mistuning and damping, changes in testing procedures, and updated requirements on material properties. The update to the ENSIP Manual is scheduled to be completed in July 2000, with the update to the JSSG to follow.

Participating Organizations: Air Force Research Laboratory (AFRL), Naval Air Systems Command (NAVAIR), NASA Glenn Research Center

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7.9 Conclusion

The Aeromechanical Characterization Action Team completed a F119 turbine rig test, which successfully measured the unsteady airflows acting on engine airfoils. In addition, a fan test rig was completed which demonstrated unsteady pressure measurements using pressure-sensitive paint. Key effort is focused on cooperative efforts across the Science & Technology (S&T), Test & Evaluation (T&E), and service engine development organizations to establish a new Joint Service Guide for High Cycle Fatigue. The guide includes materials, analysis methods, and new test protocols. The draft document is now under review.

8.0 ENGINE DEMONSTRATION

BACKGROUND

The Engine Demonstration Action Team (Engine Demo AT) has the responsibility of coordinating all the emerging HCF technologies with planned engine demonstrator targets. The engine demonstrations are responsible for acquiring the necessary data to establish, or update, the design space for the specific emerging HCF technologies so that the technology can then transition to meet user mission-specific requirements. The technology action teams will develop their specific HCF technologies to an acceptable level of risk to run on a demonstrator engine. Initial engine demonstrator planning was based on the original set of HCF technologies that was approved, and is constantly being updated as the budget and technologies change. The Demo AT has been concentrating on the turbojet/turbofan fighter engine class, which includes IHPTET demonstrator engines, JSF F119, JSF F120, and F-22 F119. Planning for the F110-129, F100-229 and other engines in the operational inventory is in process. Detail is only given on the IHPTET demonstrators because of the competitive and proprietary issues associated with the product engines.

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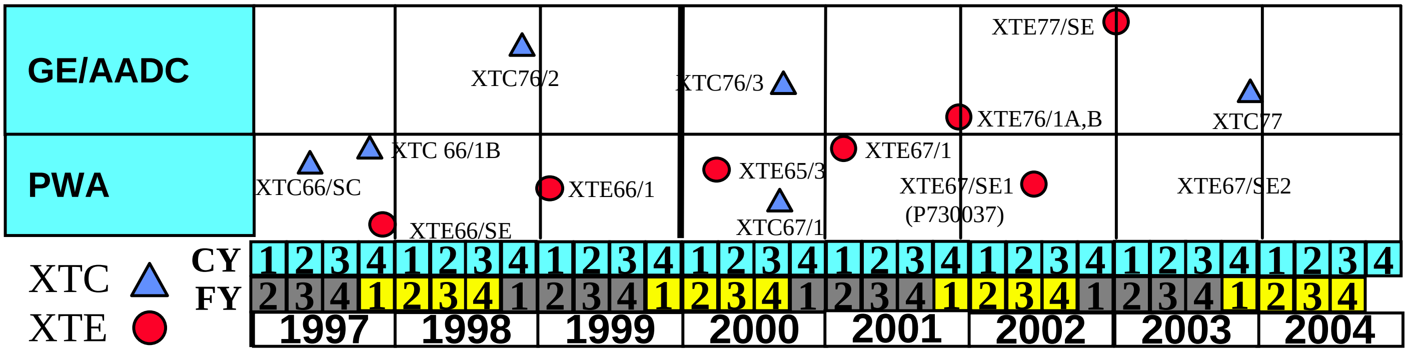
INTRODUCTION

The following pages contain tables and schedules; and descriptions of objectives, HCF technologies validated, and results of current and planned HCF engine demonstrations. The tables identify the HCF technologies and engine demonstrator targets that have been planned to date with the General Electric / Allison Advanced Development Company team and with Pratt & Whitney. In general, the engine demonstrations are planned to provide the required data to validate the HCF technology performance and to update the design codes. The action teams develop technologies, then identify them as ready for engine demonstration. These technologies are then planned for incorporation into a core or engine test, which the tables identify. Once successfully demonstrated in a core or engine, a given technology is ready for transition into a fielded engine (F100, F110, etc.) or a development engine program (F119, JSF F119, JSF F120, etc.). Core or engine demonstration of HCF technologies will continue into 2003, but in some cases specific technologies and demonstration opportunities have not been identified.

Demonstrator Engine Schedule



General Electric / Allison Advanced Development Company
Demonstration Targets

Action Team / Program Title	Engine Demonstrator					
	XTC76/2	XTE76/1	XTC76/3	XTE77SE	XTC77/1	XTE77/1
Passive Damping						
Ring Damper Design			**X**	**X**		
Mag-Spinel			**X**		**X**	
Fan Damper Design						**X****
Material Damage Tolerance						
FOD Characterization Non Laser Shock Peen				**X***		
Component Analysis						
Probabilistic Data & Correlation				**X***	**X****	**X****
Instrumentation / Health Monitoring						
LIFTP	**X***					
COPE Instrumentation		**X**				
RVM +TOA				**X****		**X****
Nonintrusive Stress Measurement System				**X****	**X****	
Environmental Mapping Validation			**X**			**X****
Component Surface Treatment						
Laser Shock Peening Validation				**X***		**X**
Forced Response Prediction System						
VBIA Analysis	**X**		**X**		**X**	**X***
HPT/LPT interactions		**X**			**X**	**X***
TACOMA Analysis & LEFF Studies				**X**	**X**	
Aeromechanical Characterization						
Pressure Mapping						**X****
X* - Research Agenda Milestones achieved						
X** - Currently Unfunded						

8.1 General Electric / Allison Advanced Development Company

The main focus of the GE/AADC demonstrator programs is to provide the test beds for the evaluation of Integrated High Performance Turbine Engine Technology Program (IHPTET) technologies and new HCF technologies. These critical core and engine demonstrations assess the performance and mechanical characteristics of HCF technologies in a realistic engine environment and provide the data necessary to validate and update advanced HCF prediction tools.

8.1.1 XTC76/2

FY 99 (1st Qtr)

Objectives: Demonstrate technologies to achieve the Integrated High Performance Turbine Engine Technology Program (IHPTET) Phase II T41 objective, variable cycle engine concept, and advanced core technologies required to meet the IHPTET Phase II thrust-weight goals.

HCF Technologies Demonstrated: The need for compressor flutter design and test methods was demonstrated.

Final Results: This test demonstrated the importance of advanced unsteady design methods for use on modern, low aspect ratio compressor airfoils, which have stability properties outside traditional experience.

Participating Organizations: Air Force Research Laboratory (AFRL), GE Aircraft Engines / Allison Advanced Development Company (AADC)

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8.1.2 XTC76/3

FY 00 (4th Qtr)

Objectives: Demonstrate The objective of this effort is to demonstrate the core technologies required to meet the IHPTET Phase II thrust-to-weight goal, and the structural durability the advanced technologies. HCF technologies to be validated in this core include unsteady aerodynamics, damping, and the Non-Interference Stress Measurement System (NSMS).

Details/Progress: Flutter analysis will be done with a fully-coupled 3D nonlinear unsteady code. REDUCE has been used to investigate mistuning in Stage 2 compressor blades. Hard damping coatings and ring dampers have been designed for this compressor. The effectiveness of these damping treatments will be evaluated on the bench and in engine testing. NSMS instrumentation will be used to gather blade response data for correlation with predictions.

Participating Organizations: Air Force Research Laboratory (AFRL), Naval Air Warfare Center (NAWC), GE Aircraft Engines / Allison Advanced Development Company (AADC)

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8.1.3 XTC77/SE

FY 03 (2nd Qtr)

Objectives: Demonstrate the integration of advanced fan and turbine technologies into an engine system and to provide an early risk reduction evaluation of Phase III technologies.

HCF Technologies to be Demonstrated: Application of laser shock peening (LSP) to forward-swept fans, unsteady aero predictions with a variety of codes, and correlation with the Non-Interference Stress Measurement System (NSMS) and other monitoring sensors, the impact of low-excitation features in front frames, application of probabilistic assessment methods.

Details/Progress: This demo was placed on contract in late 1999.

Participating Organizations: Air Force Research Laboratory (AFRL), GE Aircraft Engines / Allison Advanced Development Company (AADC)

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8.1.4 XTE76/1

FY 2002 (2nd Qtr)

Objectives: Demonstrate the integration of advanced fan and low-pressure turbine technologies into an engine system. This engine demonstration will achieve the Integrated High Performance Turbine Engine Technology Program (IHPTET) Phase II thrust-to-weight goal.

HCF Technologies to be Demonstrated: Application of advanced unsteady design methods on vaneless, counterrotating high-pressure (HP) and low-pressure (LP) turbine systems will be demonstrated. Advanced instrumentation will be used to gather unsteady data on the HP/LP turbine system.

Details/Progress: Hardware is currently being fabricated in preparation for the engine demonstration.

Participating Organizations: Air Force Research Laboratory (AFRL), GE Aircraft Engines / Allison Advanced Development Company (AADC)

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8.1.5 XTC77

FY 2004 (1st Qtr)

Objectives: Demonstrate the technologies required to achieve the Integrated High Performance Turbine Engine Technology Program (IHPTET) Phase III thrust-to-weight goal.

HCF Technologies to be Demonstrated: advanced technologies in the areas of damping, instrumentation, and design methods, including probabilistic and unsteady aerodynamics.

Details/Progress: This effort is in the preliminary design phase.

Participating Organizations: Air Force Research Laboratory (AFRL), GE Aircraft Engines / Allison Advanced Development Company (AADC)

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Pratt & Whitney
Demonstration Targets

Passive Damping								
High Effectiveness Turbine Damping				X			X	X
IBR Dampers					X			X
Material Damage Tolerance								
Titanium Demonstration						X		
Single Crystal Demonstration							X	X
Gamma-Ti Demonstration		X			X		X	
Component Analysis								
Probabilistic HCF Assessment							X	X
FEM Modeling Enhancements	X	X	X	X	X	X	X	X
Instrumentation / Health Monitoring								
Generation IV NSMS					X		X	
Non-Optical NSMS	X						X	
Advanced Pyrometry					X			
Component Surface Treatment								
LSP Demonstration						X		
Forced Response Prediction System								
Robust Airfoil Design / FLARES	X		X	X	X		X	
Aeromechanical Characterization								
HCF Design Tool Eval/Tech Transition								X
X - Research Agenda Milestones achieved								

8.2 Pratt & Whitney

The main benefit of the P&W demonstrator programs to the HCF Initiative is to provide the test beds for the initial evaluation of new HCF technologies. These critical core and engine demonstrations, in addition to demonstrating improved thrust-to-weight and providing a validation for technology transition candidates, assess the performance and mechanical characteristics of HCF technologies in a realistic engine environment and provide the data necessary to validate and update advanced HCF prediction tools.

8.2.1 XTE66/A1

FY 95 (4th Qtr)

Objectives: Validate the F119 Hollow Fan Blade integrally bladed rotor (IBR) in an engine environment.

HCF Technologies Demonstrated: unsteady aerodynamic and forced response (FLARES) codes, first-generation eddy current sensor

Final Results: HCF tools correctly identified root cause and fix for unacceptable rotor response. Demonstration of the eddy current sensor to measure blade tip response was successfully completed.

Participating Organizations: Air Force Research Laboratory (AFRL), Pratt & Whitney Independent Research & Development (P&W IR&D)

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8.2.2 XTC66/SC

FY 97 (3rd Qtr)

Objectives: Demonstrate and evaluate F119 technology transition, Joint Strike Fighter (JSF) technology maturation risk reduction, and Integrated High Performance Turbine Engine Technology Program (IHPTET) technologies.

HCF Technologies Demonstrated: robustness of gamma-TiAl high-pressure compressor (HPC) blades, supercooled high-pressure turbine (HPT) blades

Final Results: Testing demonstrated the HCF robustness of gamma-TiAl blades and supercooling technologies.

Participating Organizations: Air Force Research Laboratory (AFRL), Naval Air Warfare Center (NAWC), Pratt & Whitney

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8.2.3 XTC66/1B

FY 98 (1st Qtr)

Objectives: Demonstrate temperature, speed, and structural capability of the core to run Integrated High Performance Turbine Engine Technology Program (IHPTET) Phase II conditions and evaluate the aerodynamic and thermodynamic performance of the high-pressure compressor (HPC), Diffuser/ Combustor, and high-pressure turbine (HPT).

HCF Technologies Demonstrated: unsteady aerodynamic (NASTAR V3.0) and forced response (FLARES V1.0) codes

Final Results: Testing provided benchmark data for analytical tool calibration and validation. Data have been used to establish code performance against Action Team metrics.

Participating Organizations: Air Force Research Laboratory (AFRL), Pratt & Whitney

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8.2.4 XTE66/1

FY 99 (2nd Qtr)

Objectives: (1) Demonstrate the Integrated High Performance Turbine Engine Technology Program (IHPTET) Phase II thrust-to-weight goal. (2) Provide initial engine demonstration of a vaneless counter-rotating turbine and microwave augmentor.

HCF Technologies Demonstrated: internal low-pressure turbine (LPT) dampers for control of high-frequency excitation

Final Results: A counter-rotating vaneless turbine was successfully demonstrated. Low turbine (LPT2) blade stresses were low in higher-order modes. The configuration was evaluated with FLARES for comparison to Action Team metrics.

Participating Organizations: Air Force Research Laboratory (AFRL), Pratt & Whitney

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8.2.5 XTC67/1
FY 00 (4th Qtr)

Objectives: Demonstrate the temperature, speed, and structural capability of the core to run Integrated High Performance Turbine Engine Technology Program (IHPTET) Phase II and some early Phase III conditions and to evaluate the high-pressure compressor (HPC), Diffuser/Combustor, and high-pressure turbine (HPT) aerodynamic and thermodynamic performance.

HCF Technologies to be Demonstrated: Generation 4 Non-Interference Stress Measurement System (NSMS,) Advanced Pyrometry, Finite Element Modeling (FEM) Enhancements, the FLARES (V2.0) Code, Asymmetric high-pressure compressor (HPC) Stators, Comprehensive Engine Condition Management (CECM), improved platform dampers in the high-pressure turbine (HPT)

Progress to Date: The final design was completed and reviewed by the government in the fourth quarter of 1998 and hardware fabrication is in progress.

Participating Organizations: Air Force Research Laboratory (AFRL), Pratt & Whitney

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8.2.6 XTE66/SE

FY 98 (1st Qtr)

Objectives: Demonstrate the structural durability of Integrated High Performance Turbine Engine Technology Program (IHPTET) technologies in an F119 engine and to transition some of those technologies to the F119 for the F-22 or Joint Strike Fighter (JSF) aircraft. The demonstration was an accelerated mission test (AMT) using an F-22 IFR mission.

HCF Technologies Demonstrated: robustness of gamma-Ti Compressor Blades, Supervanes and Superblades

Final Results: The engine completed 1505 AMT TACs and most of the technology component hardware met durability predictions.

Participating Organizations: Air Force Research Laboratory (AFRL), Naval Air Warfare Center (NAWC), Pratt & Whitney

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8.2.7 XTE67/1

FY 01 (2^{nd} Qtr)

Objectives: Demonstrate the temperature, speed, and structural capability of the engine to run early Integrated High Performance Turbine Engine Technology Program (IHPTET) Phase III conditions and evaluate the low spool and integrated aerodynamic and thermodynamic performance.

HCF Technologies to be Demonstrated: Integrally bladed rotors (IBRs) designed for low resonant stress and flutter response, IBR damping, lightweight turbine dampers, and high-temperature eddy current sensors will be validated. Analytical tools to be applied during the XTE67/1 design include unsteady aerodynamics, FLARES (V2.0), MDA, BDAMPER (V7.0), and CDAMP (V2.0).

Progress to Date: The final design review for XTE67/1 was held in November 1999.

Participating Organizations: Air Force Research Laboratory (AFRL), Naval Air Warfare Center (NAWC), Pratt & Whitney

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8.2.8 XTE65/3

FY 00 (2nd Qtr)

Objectives / HCF Technologies to be Demonstrated: (1) Demonstrate the utility and accuracy of new fan blade damage tolerance HCF tools during engine testing of damaged blades. (2) Evaluate benefits of laser shock peening of titanium integrally bladed rotors (IBRs) to mitigate damage-induced fatigue debits.

Progress to Date: The rotor 1 IBR has been laser peened (3 blades). The fan rotor is currently at the vendor for installation of strain and crack detection gages.

Participating Organizations: Air Force Research Laboratory (AFRL), Pratt & Whitney Independent Research & Development (P&W IR&D)

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8.3 Conclusion

Several advanced development technology demonstrator programs provided the test beds for evaluation of new HCF technologies. Both core and full engine tests were conducted at Pratt & Whitney facilities to characterize hollow fan blade integrally bladed rotor (IBR) designs and to evaluate forced response codes (such as FLARES), new eddy current sensors, and advanced internal low-pressure turbine dampers for control of high-frequency excitation. Advanced technology core engine testing at General Electric facilities over the last year has also highlighted the importance of advanced unsteady design methods for use in modern low-aspect-ratio compressor airfoils, which have stability properties outside traditional experience. In all cases, testing provided key benchmark data for analytical tool calibration along with initial HCF robustness characterization of multiple new technologies.